Habitat Suitability Modeling of Asian-Moon Scallop (Amusium pleuronectes) in Brebes District Waters, Central Java, Indonesia

by Jusup Suprijanto

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Habitat Suitability Modeling of Asian-Moon Scallop (*Amusium pleuronectes*) in Brebes District Waters, Central Java, Indonesia

Achmad Sahri ✉, Sutrisno Anggoro, Jusup Suprijanto

Master Program of Coastal Resources Management, Diponegoro University, Semarang, Indonesia

✉ Corresponding author email: achmad.sahri69@gmail.com

Abstract The purpose of this study was to analyze the characteristics of the environment that determines the bottom habitat of the scallop from Brebes District and to map the potential habitat of scallop using spatial modeling. Research areas include the waters covering 806.03 km^2 of Brebes District extending 12 miles outward the sea. Habitat suitability mapping was conducted using Ecological Niche Factor Analysis (ENFA). Kolmogorov-Smirnov test was used to test differences in each environment occupied by scallop with the overall study area.

ENFA results showed that the scallop required habitats with very different conditions from the mean habitat conditions existing in all study areas (p <0.05). The suitable habitat for scallop *Amusium pleuronectes* in Brebes District waters were the bottom water column with high plankton density (11,001-14,500 ind/L), between 18-31 m of water depth, low total suspended solids (<3.61 mg/L), soft sediments substrate (mud, φ ≥ 6) and a relative distant from estuary (> 5 km). In addition, the scallop also required bottom waters habitat with current velocity and high salinity (> 0.06 m/sec; 31.85-32.65 ‰) and low temperature of the bottom waters (29.92-30.06 °C), while towards the pH level of the bottom waters, scallop were relatively more tolerant (7.3-7.4). Based on spatial modeling of habitat suitability in the study area, there were three categories obtained: 1) "suitable habitat" area of 4,629.01 ha (5.8%), 2) "marginal habitat" area of 9,291.09 ha (11.5%), and 3) "unsuitable habitat" for scallops covering an area of 66,682.68 ha (82.7%).

Keywords *Amusium pleuronectes*; ENFA; Habitat modeling; GIS; Scallop

Introduction

Scallop is one of the fisheries resources that have the potential to be exploited optimally as it has a high economic value in the international trade. Some destination countries for export purpose of scallop from Indonesia include Singapore, Taiwan and Hong Kong (Suprijanto, 2003; Prasetya, 2009). On the north coast of Central Java, Brebes District is one of the areas known as a significant scallop producer, because in certain seasons, scallop from this area has managed to meet the supply needs of exporters both in Jakarta and in domestic market.

One of the distinguished constraints of fishing effort, and exporting the scallop is the continuity of production that has not sustained yet. It is due to the fishing season factor (Prasetya, 2009; Widowati et al., 2008) as well as the lack of information on what kind of waters preference for their habitat.

Knowledge of scallop habitat characteristics, such as sediment type, depth, current speed, total suspended solid (TSS), salinity, and temperature (Franklin et al., 1980; Williams, 2002), can be a valuable guide in determining their habitat. By knowing the characteristics of scallop habitat, the mapping of areas as their potential habitat can be easily performed.

Some researches on mapping the potential of scallop have been carried out in several countries such as Queensland (Williams, 2002) and the U.S. (Hart, 2006). Meanwhile in Indonesia, the mapping potential of scallop, especially regarding the suitability of the habitat has become less concerned.

Habitat mapping of scallop can provide several advantages, including obtaining an estimation of how great the potential of the water areas that is suitable for habitat scallop is. Prasetya (2009) reported that assessing the potential of scallop in Brebes District

waters is one of the most important priorities in resource management. Wilson et al. (2007) implied that the exploitation activity of marine resources both commercially and sustainably required information on habitat mapping. By knowing the habitat of scallop, the fishing ground of them can be located, so that the efficiency of fishing effort can be accomplished. In addition, habitat suitability maps can also be applied as a database for conservation and resource management (Danker et al., 2001; Compton, 2004; Leverette, 2004; Mangeberg, 2004; Bryan and Metaxas, 2007; Wilson et al., 2007; MacLeod et al., 2008; Praca and Gannier, 2008).

As benthic marine organism, a specific method in mapping the areas of scallop habitat is required in order to describe the precise and appropriate benthic environment. Habitat suitability maps can be generated through spatial habitat modeling, which is a method examining the relationship between the presence and/or the absence of species with relevant environmental parameters termed as eco-geographical variables (EGV) (Hirzel, 2001; Hirzel et al., 2002) forming the basis of environmental variables waters. The program is also capable of performing descriptive statistical analysis and GIS-based. Therefore, it will be able to deliver a habitat suitability map.

This study aimed to analyze the characteristics of the benthic environment that determines the scallop habitat and maps the potential habitat using spatial modeling based on the environmental parameters, so the potential habitats for scallop is acquainted.

1 Material and Method
1.1 Types and Sources of Data
Primary data were obtained directly from the field such as the environmental parameters of the seabed and the surface including: plankton, sediment, temperature, depth, and distance from the estuary along with suspended solids, salinity and pH. Scallop samples and catching coordinate data were also collected as validation of the established habitat suitability models.

Secondary data were collected by reviewing some related literature sources. In addition, satellite data and supporting maps were obtained from several local agencies and institutes. Those satellites data included: the 2008 ASTER satellite images, the 2009 Landsat 7

ETM+ satellite images, the 2002 Java Sea Bathymetry Map from Hydro-Oceanographic Office of Indonesian Navy (Dishidros), the 1991 Distribution of Sediment Surface Seabed Map from the Marine Geology Research and Development Centre (P3GL), the 2001 Topography Map from Geospatial Information Agency (Bakosurtanal), the 2010 tidal data from Dishidros, the 2010 wind data of Meteorology, Climatology and Geophysics Agency (BMKG) of Tegal. Then, other supporting data on the study area originated from Department of Marine and Fisheries Affairs (DKP) of Brebes District and previous researches were also collected.

1.2 Data Analysis Methods
Some data such as tentative maps from the secondary data were analyzed before the survey. Those data included the shoreline updating with ASTER satellite image and the seabed sediments mapping by using the digit on screen method (Prahasta, 2002; Nuarsa, 2005), the depth mapping by applying the interpolation model of Inverse Distance Weighted (IDW) in geostatistics-ArcGIS (ESRI, 2000; Prahasta, 2002; Radiarta et al., 2003). The TSS data extraction from Landsat 7 ETM+ satellite image and the tides modeling with the SMS program (Luetich and Westerink, 2004; Nugroho, 2005) were also analyzed.

Samples obtained from the field survey were analyzed in the laboratory, including: seabed sediment samples by multilevel sieve (sieve shaker) method-pipetting (Tahrir et al., 1986) and sediment classification triangle diagram (Folk, 1980). Then, plankton samples by APHA method (1976) based on the type of plankton identification book of Yamaji (1984), as well as the TSS samples of the sea surface by spectrophotometer at 810 nm wavelength and distilled water as a blank (APHA, 1980).

Mapping of estuary ranged by using the buffering technique in geostatistics-ArcGIS (ESRI, 2000; Prahasta, 2001), the spatial mapping of seabed environmental parameters with IDW method in geostatistics-ArcGIS (ESRI, 2000), the mapping of scallop availability with Generate Random Point models contained in the program Animal Movement SA v2.04 beta in ArcView 3.3 software, as well as habitat modeling were made to determine the suitability of habitat scallop with ENFA.

The species availability map was created by converting the presence of 3.366 data of scallop into a grid size of 100×100 m^2 with ArcGIS software. The grid conversion has resulted 721 species presence grids.

1.3 Scallop Habitat Modeling with ENFA

Habitat suitability map generated by Ecological Niche Factor Analysis (ENFA). ENFA could produce habitat suitability maps with the data linking to the species availability with environmental variables (Table 1) in order to determine the ecological niche of a species (Hirzel et al., 2002). This technique integrated in the BioMapper software (Hirzel, 2001). The program also combined descriptive statistics with Geographic Information Systems (GIS).

Table 1 Eco-geographical variable applied in the ENFA

Eco-geographical Variables	Data Source	Data Synthesis Method
Seabed Sediments	Distribution of seabed sediment type from P3GL	The sediment type data was digitized and converted to a raster format then transformed to φ Wentworth (Williams et al., 2006)
Bathymetry	Points data and depth contours of bathymetry map from Dishidros	Data interpolation with IDW method in geostatistic-ArcGIS
Distance from Estuary	Indonesia topographic map from Bakosurtanal updated with 2008 ASTER satellite image	Synthesis data by *buffering* method in geostatistics-ArcGIS
Sea Surface TSS	Sea water sampling analyzed in laboratory	Extracted from Landsat 7 ETM+ satellite image by generating the TSS Algorithm
Seabed Current Velocity	Hourly wind data from BMG; Bathymetry and tidal data from Dishidros; Coastline of 2008 Aster satellite image	SMS 8.1 Modeling
Seabed Temperature Seabed Salinity	Primary data obtained by *in-situ* analysis using CTD+	Data interpolation with IDW method in geostatistics-ArcGIS
Seabed Acidity (pH)	Primary data obtained by *in-situ* analysis using *pH-meter*. Water was sampled using Nansen Bottle	Data interpolation with IDW method in geostatistics-ArcGIS
Seabed Plankton Density	Seabed planktons maintained in Nansen Bottle was analyzed in the laboratory	Data interpolation with IDW method in geostatistics-ArcGIS

Note: All data were converted into raster data with 100×100 m^2 grid size

In BioMapper, each variables value will be transformed to Box-Cox format, thereby it normally distributed and could be overlaid. For each thematic map, the value of each location where scallop species calculated produced a score appearing as several classes in the frequency histogram. By assuming the data distributed normally, the maximum score was around the median and decreased on both sides (Hirzel et al., 2002). Hereafter, class of each grid within the study area would be determined and the value of "partial suitability" of each thematic map was generated based on scores from classes in the histogram. The farther the grid from the median, the lower the habitat suitability was.

Furthermore, global suitability maps would be generated by calculating the weighted averages of several partial suitability value of each thematic map, producing a rescaled habitat suitability index value in the isopleths methods ranging from 0-100, where a value of 0 indicated that there were no suitable habitat and vice versa (Hirzel, 2001). ENFA summarized all eco-geographical variables (thematic maps) into a number of unrelated components with each other, such as Principal Component Analysis (PCA) (Manly, 1986; Reutter et al., 2003). These components represented the combined factors explaining variability. One thing that distinguished ENFA from PCA was the formed components had a direct ecological significance.

The first component referred to as species ecological niche marginality (marginality) which described the distribution of species in relation to the mean of global distribution (study area). The higher the marginality coefficient, the different the habitats of species from the average condition of environmental variable in the study area showed. Marginality coefficient was determined as the absolute difference between the

global mean and the mean of each species to environmental variables (Hirzel et al., 2002), calculated with the Equation (1).

$$M = \frac{|m_G - m_S|}{1.96\sigma_G} \dots\dots\dots\dots (1)$$

M = marginality

m_G = global mean (study area)

m_S = species mean

σ_G = standard deviation of the global distribution

By combining the marginality coefficient of each environmental variable, then ENFA calculated the coefficient of Total Marginality (M_T) (Hirzel et al., 2002), represented with Equation (2).

$$M_T = \frac{\sqrt{\sum_{i=1}^{V} m_i^2}}{1.96} \dots\dots\dots\dots (2)$$

V = number of environmental variables

m_i = marginality coefficient of an environment variable i.

The second and following components were species specialization factors indicating how limited the ecological niches of species was related to the study area. The higher value of specialization in an environmental variable indicated that the species required a narrow range of environmental variables. Its value defined as the ratio of the global distribution of the variance species of environmental variables (Figure 1, 2) (Hirzel et al., 2002) and calculated by Equation (3).

$$S = \frac{\sigma_G}{\sigma_S} \dots\dots\dots\dots (3)$$

S = specialization for an environmental variable

σ_G = standard deviation of the global distribution

σ_S = standard deviation of the species distribution

Analog to the Total Marginality, Total Specialization coefficient (S_T) could also be calculated by combining the specialization coefficient of each environmental variable and calculated with Equation (4).
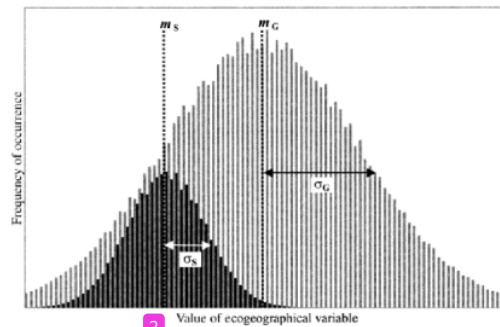

Figure 1 The distribution of the focal species on any eco-geographical variable (black bars) may differ from that of the whole set of cells (gray bars) with respect to its mean ($m_S \neq m_G$), thus allowing marginality to be defined. It may also differ with respect to standard deviations ($\sigma s \neq \sigma_G$), thus allowing specialization to be defined (Hirzel et al., 2002)

$$S_T = \frac{\sqrt{\sum_{i=1}^{V} \lambda_i}}{V} \dots\dots\dots\dots (4)$$

V = number of environmental variables

λ_i = specialization coefficient of an environmental variable i.

Total Tolerance coefficient, opposed to the Total Specialization coefficient ($1/S_T$), ranged from 0-1, where the higher coefficient indicated the more extensive ecological niches of species. In other words, species were more tolerant to the environmental variables. Marginality and specialization coefficients would be calculated directly by BioMapper program. The output of this program generated habitat suitability maps of scallop accompanied with the factors analysis explaining the role of environmental variables in determining the suitability of seabed habitat.

In order to assess the ENFA model ability to generate habitat suitability map, Continuous Boyce Index was applied to evaluate the model (Hirzel et al., 2006) which was a cross-validation with presence-only data. Species availability data were divided into 10 parts of the same data sets. Nine of the 10 data sets used to calibrate habitat suitability maps, while the remaining 1 dataset used for validating the results. This procedure was repeated 10 times. From the ten subsets the number of cells which fall into a set number of HS value bin ranges was calculated. Each bin covers a portion of the maps area (Ai), and contains some proportion of the validation cells (Ni).
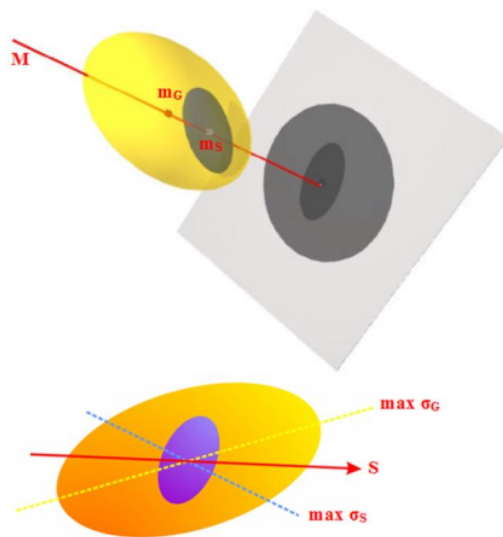
Figure 2 Geometric interpretation of ENFA: Large gray circles represented the entire cell space (global), while the smaller dark circles represented parts of the cells of studied species. Straight line passing through the midpoint of the two spaces (m_G and m_S) was the marginality factor (M), while the specialization factor (S) was the axis maximizing the ratio of the global variance (σ_G) with variance species (σ_S), which was the mean value of maximum global variance with a minimum species variance (Modified from Hirzel et al., 2002)

The area-adjusted frequency of cells falling into each bin range can then be computed as Fi=Ni/Ai. A completely random map would result in Fi≈1 for each bin range. A good fit of the data to the model is indicated by a low Fi for low HS values and a high Fi for high HS values (Hirzel et al., 2006). Range of habitat suitability scale in this study was divided into three classes according to Compton (2004):

Suitable habitat, the habitat suitability valued between 67 and 100.

Marginal habitat, the habitat suitability valued between 34 and 66.

Unsuitable habitat, the habitat suitability valued between 0 and 33.

Evaluation/validation of habitat suitability models along with the data was using Area Under receiver-operating-characteristic Curve (AUC). This validation technique was cross-validation with

presence-absence data to assess the accuracy of the ENFA model. The relevant techniques were used, if the species absence data was sufficiently reliable. AUC values ranged from 0 to 1 with values close to 1 indicated a very good accuracy from the model (Hirzel et al., 2006). Evaluation of both models with continuous Boyce index method and the AUC had also been integrated in the program BioMapper, so the results could be seen directly from the program output. Furthermore, to determine whether there were differences in each environmental variable occupied by scallop with the overall study area, then the chi-square test was applied (χ^2). If the data characteristics did not allow for the chi-square test to be conducted, then the Kolmogorov-Smirnov test became the alternative. Range of values for each environmental variable was divided into classes with same interval. By using the ArcGIS, the location frequency (grid) in each class was calculated both for environmental variable from the entire study area and the location frequency (grid) where scallop located (Leverette, 2004).

2 Results
2.1 Characteristics of Scallop Habitat Environmental
Nine characteristics of environmental (eco-geographical) variables which determined the scallop habitat were presented in Figure 3, while the distribution of scallop in classes in each of these variables was presented in Figure 4.

Distribution of scallop at the study area based on the eco-geographical variable was seabed with high density of plankton (11,001-14,500 ind/L), between 18-31 m water depth, low TSS (< 3.61 mg/L), soft sediments (mud, φ ≥ 6) and a relative distant from estuary (> 5 km). In addition, the scallop also required benthic habitat with high current velocity and salinity (> 0.06 m/sec; 31.85-32.65 ‰) and relatively low temperature (29.92-30.06 °C). Meanwhile, scallops were relatively more tolerant to the pH (7.3-7.4).

2.2 Suitability and Potential Habitat of Scallop
Ecological Niche Factor Analysis using 5 eco-geographical variables showed Total Marginality value of 1.069 (Table 2), indicating that the scallop required habitats with very different conditions from the mean habitat conditions existing throughout the study area. Scallop habitat in the study area was largely
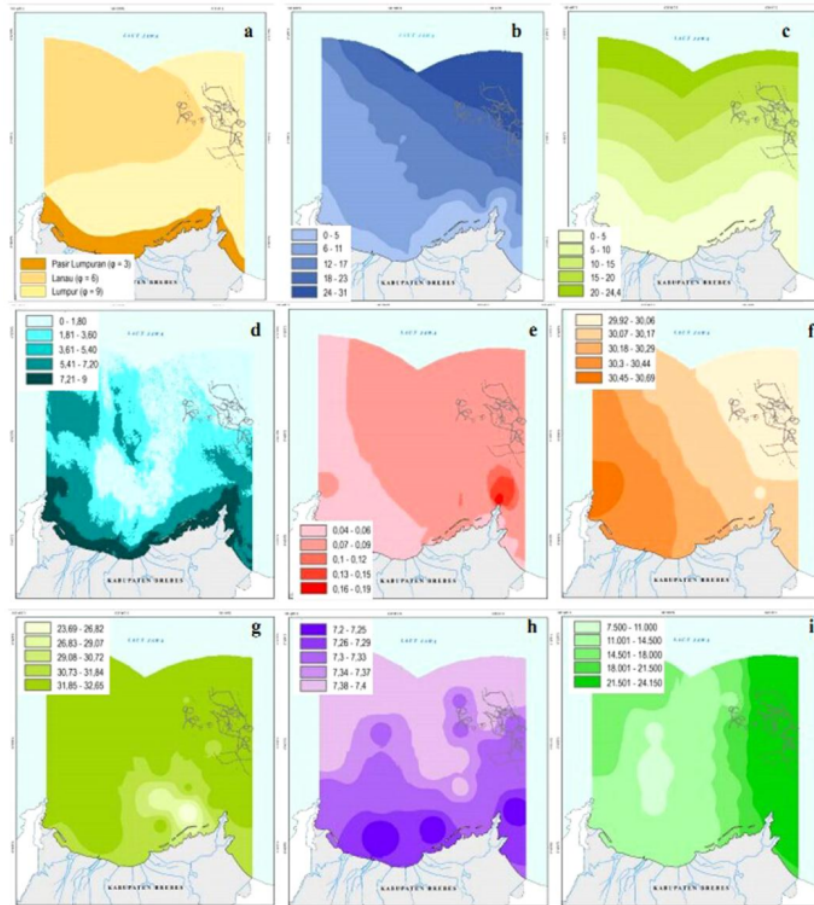
Figure 3 Eco-geographical variable spatial distribution maps: a. seabed sediments (φ); b. depth (m); c. distance from estuary (km); d. sea surface TSS (mg/L); e. seabed current velocity (m/sec); f. seabed temperature (°C); g. seabed salinity (‰); h. seabed pH; and i. seabed plankton density (ind/L) in Brebes District with scallop distribution locations. Kabupaten Brebes=Brebes District, Laut Jawa=Java Sea, Pasir Lumpuran=Muddy Sand, Lanau=Silt, Lumpur=Mud

Table 2 Total Marginality, Total Specialization and Total Tolerance resulted by ENFA

Total Marginality (M_T)	1.069
Total Specialization (S_T)	3.822
Total Tolerance ($1/S_T$)	0.262

determined by the high plankton density (m = 0.657) and deeper water depths (m = 0.596) (Table 3).

TSS variables and seabed sediments with relatively equal weight determined the habitat of scallop on the next order. Scallop preferred waters with a lower

Table 3 Marginality and specialization coefficient of 5 variables used for ENFA

Eco-geographical Variable	Marginality (59.1%)	Specialization			
		1 (21.9%)	2 (11.6%)	3 (4.8%)	4 (2.6%)
Depth (m)	**0.596**	**0.458**	-0.478	0.735	-0.382
Distance from estuary (km)	0.130	**-0.747**	-0.379	-0.264	0.415
TSS (mg/L)	**-0.314**	-0.180	-0.356	0.524	0.494
Plankton (ind/L)	**0.657**	**-0.422**	0.550	-0.334	0.200
Sediment (φ)	0.312	0.146	-0.445	-0.062	0.631

content of TSS than the average TSS content of study area (m = -0.314), and preferred sediments with larger φ values (finer sediment) than the sediments average
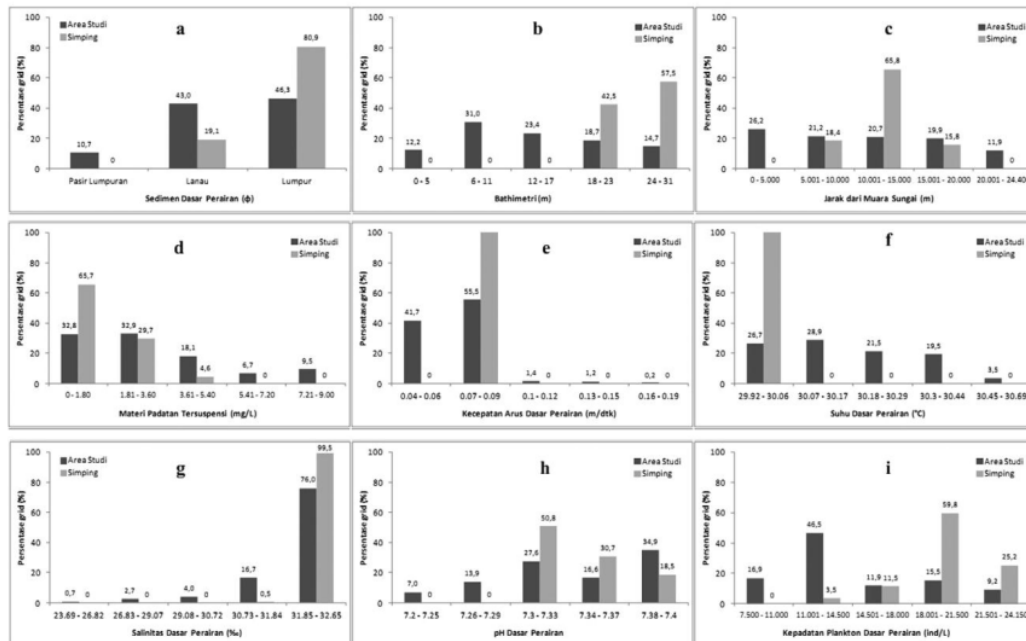
Figure 4 Distribution of grid inhabited by scallop based on the eco-geographical variables in Brebes District: a. sedimen dasar perairan (seabed sediments, φ); b. bathimetri (bathymetry, m); c. jarak dari muara sungai (distance from estuary, km); d. materi padatan tersuspensi (TSS, mg/L); e. kecepatan arus dasar perairan (seabed current velocity, m/sec); f. suhu dasar perairan (seabed temperature, °C); g. salinitas dasar perairan (seabed salinity, ‰); h. pH dasar perairan (seabed pH); and i. kepadatan plankton dasar perairan (seabed plankton density, ind/L). Persentase grid=Grid percentage (%), Area studi=Study area, Simping=scallop, Pasir Lumpuran=Muddy Sand, Lanau=Silt, Lumpur=Mud

size of study area (m = 0.312). Marginality coefficient of the estuary distance variable was relatively smaller. This showed that scallop habitat just slightly different from the average of study area for that variable. Marginality values of the five variables were able to explain 59.1 % of the overall variability of the data (Table 3).

Specialization coefficient indicated that the habitat of scallop had a relatively narrow range in the distance of estuary (-0.747), depth (0.458) and plankton density (−0.422) (Table 3). This proved that the ecological niches of scallop were relatively limited to three variables.

Although the data of current velocity, temperature, salinity and pH of the seabed were available but due to the narrow range of possible values, these variables were not included in the ENFA (Leverette, 2004). Mean value comparison technique and Kolmogorov-Smirnov test between the study area and the location where the scallop on each variable could be used to

assess the trends in habitat preference. As a result, the mean current velocity at the location inhabited by scallop was higher than the mean current velocity of study area. Same case happened with the average value of salinity. In contrary, the average temperature at the location of scallop was lower than the average temperature of the study area. While the average pH value was relatively similar between the study areas with the location inhabited by scallop (Table 4).

Kolmogorov-Smirnov test results showed that between the location inhabited by the scallop and the entire study area were significantly different for all environmental variables applied (p <0.05, Table 5). This was also evidenced by the large value of Total Specialization (3.822), while the value of its Total Tolerance was relatively low (0.262) (Table 2), indicating that the scallop had a narrow ecological niche and had a relatively low tolerance towards its environmental conditions.

Table 4 Value of each environmental variable of the study area and that of location inhabited by scallop. SD=standard deviation

Eco-geographical Variable	Average of Study Area	SD of Study Area	Average of Scallop	SD of Scallop
Sediment (φ)	7.07	2.00	8.43	1.18
Depth (m)	14.22	7.65	23.84	1.90
Distance from Estuary (km)	10.85	6.85	12.55	2.60
TSS (mg/L)	4.09	2.25	2.50	1.03
Current Velocity (m/sec)	0.07	0.02	0.08	~0
Temperature (°C)	30.17	0.15	29.99	0.03
Salinity (‰)	31.88	1.00	32.38	0.19
pH	7.34	0.05	7.34	0.03
Plankton (ind/L)	14,666	4,092	20,396	2,124

Table 5 Kolmogorov-Smirnov test results in assessing the differences between characteristics of the environmental variables inhabited by scallop with the whole study area

Eco-geographical Variable	df	Kolmogorov-Smirnov Z	Critical Value of Z	p
Sediment (φ)	2	11.12	0.84	< 0.05
Depth (m)	4	21.47	0.62	< 0.05
Distance from Estuary (km)	4	9.35	0.62	< 0.05
TSS (mg/L)	4	10.61	0.62	< 0.05
Current Velocity (m/sec)	4	13.42	0.62	< 0.05
Temperature (°C)	4	23.63	0.62	< 0.05
Salinity (‰)	4	7.59	0.62	< 0.05
pH	4	6.73	0.62	< 0.05
Plankton (ind/L)	4	19.41	0.62	< 0.05

ENFA model validation by using AUC method showed values of 0.94 (~1), thus the ENFA model was accurate and very good (Hirzel et al., 2006). Habitat suitability map of ENFA results was presented in Figure 5.

The result of spatial modeling and ENFA was habitat suitability maps of scallop in Brebes District with three suitability categories: suitable habitat, marginal habitat and not-habitat. The suitable habitat for the scallop was the seabed of the eastern study area located relatively far ahead Pemali estuary (Figure 5), while "marginal habitat" was around the "suitable habitat". Both of these habitat suitability categories each of them covered an area of 5.8% and 11.5% of the whole study area (Table 6).

3 Discussion

Scallop at the study area were not evenly distributed. They only inhabited a specific location (Figure 5) with certain range of environmental variables determining its habitat (Table 4). Research conducted in more extensive waters wider (from Semarang to Tegal), also

Figure 5 Habitat suitability map of *Amusium pleuronectes* in Brebes resulted by spatial modeling and ENFA. Kabupaten Brebes=Brebes District, Laut Jawa=Java Sea

Table 6 Habitat suitability category of scallop in Brebes District by spatial modeling and ENFA

Habitat Suitability Score	Suitability Category	Area (ha)	Percentage (%)
67 - 100	Suitable Habitat	4,629.01	5.8
34 - 66	Marginal Habitat	9,291.09	11.5
0 - 33	Unsuitable Habitat	66,682.68	82.7

showed that the distribution of scallop in the waters tended to be clumped, found only in certain locations (Abdillah, 2000).

The application of some environmental variables in determining the habitat of scallop was performed because of the multidimensional characteristic shown by the ecological niche of a species in nature (Begon et al., 2006). ENFA results showed that the scallop habitat at the study area preferred waters with higher density of plankton, the deeper depth, lower suspended solids materials, finer sediment (mud) and a more distant from estuary than the average study

area for these variables (Table 4, 5). In addition, the scallop also required seabed habitat with higher current velocity and salinity; lower temperature than the average study area for these variables. Furthermore, scallop was relatively more tolerant to pH (Table 4, 5).

The highest density of plankton in the seabed of Brebes District was found in the front of the wider estuary, especially in front of Pemali River in the eastern part (Figure 3i, 4i). The high density of plankton was allegedly associated with nutrient input due to activity on the mainland, where majority of land use along the coastal of Brebes Districts was ponds. Whilst in the upper area, the activity was dominated by agricultural which generally used fertilizers. Nutrients from those two activities stimulated the plankton growth.

The high density of plankton in the entire water column was because the water was relatively shallow (Figure 3b), therefore it was still part of the euphotic zone, especially in areas that was distant enough from the mainland where its suspended solids material tended to be low (Figure 3d). In the euphotic zone, plankton could still live because they got the sunlight allowing them for photosynthesis (Fachrul, 2007).

Plankton was successfully screened using 25 plankton net classified in micro-plankton, namely plankton with 20-200 μm in size (Omori and Ikeda, 1992). Lucas et al., 1987) stated that the cumulative weight of plankton above 20 μm indicated that it was relatively large, making it easier to sink and become a food source for filter-feeder organisms, including scallop.

The largest constituent of the phytoplankton community of seabed in the study area was from the class Bacillariophyceae (diatoms), with Chaetoceros, Nitzchia, and Skeletonema were the three genus commonly found in each observed station. Diatoms were the largest constituent of plankton in the sea, so its role as a dominant source of food. Chaetoceros and Skeletonema were two plankton species widely used as feed in marine aquaculture.

Scallop habitat required relatively deep waters and a suitable location was found only in the eastern part of the study area (Figure 3b, 4b). This depth was relatively similar to the results reported by Widowati

et al. (1999), where the waters scallop in Pekalongan, commonly found at depths of 20-30 m. This kind of habitat preferences was assumed to be related to the temperature suitability of the seabed waters for a place to live for scallop. The deeper the water depth was, the lower temperature would be (Figure 3f, 4f).

Spatially, TSS in Brebes District marine waters had spread widely, with the highest content was in the front of Cisanggarung in the western and Pemali River estuary in the eastern side of the study area. This was due to the presence of suspended solid flowing in to the water column through the river stream. In addition, factors such as physical oceanography and tidal currents also affected the high turbidity levels in the area. During the high tide to the low one, the sediment carried by the flow of the river would be suspended in to the water column. Thus, it increased the level of turbidity in the waters around the mouth of the river (Triatmodjo, 1999).

Scallop were mostly obtained from the location with very low (< 1.80 mg/L) and low (1.81-3.60 mg/L) content of TSS indicating that the scallop preferred areas with low content of TSS as its habitat. This location was distant from the mainland, especially in the eastern side of the study area (Figure 3d, 4d).

In general, the seabed at the study area was dominated by fine substrates (silt and mud), as well as scallop habitat. Numbers of rivers streaming down into the coastal around the study area influenced the type of sediment on the seabed. There was 13 rivers streaming from the mainland of Brebes District (DKP, 2008). The dominance of these fine substrates occurred due to deposition of material originated from weak energy because of the flat riverbed. Fine-textured sediments such as silt and mud were generally darker in color because they contained higher organic materials (Astjario et al., 1990). Fine-textured sediments were also rich in plankton such as diatoms (Thomas, 1997), so it became a food source for benthic consumers (Sukhtankar, 2004) including for scallop.

Franklin et al. (1980) reported that *Amusium* sp. could live on the surface of the seabed with varying substrate types ranging from rocky until muddy substrate and mostly found in sandy substrates mixed with shells. However, in the study area, scallop *A.*

pleuronectes were mostly found in mud and silt substrates (Figure 3a, 4a).

Although there was no direct influence towards the scallop growth, type of sediment might be expected to affect the distribution associated with its ability to adapt. Study on the sediment types of Brebes District in 1986 (Tahrir et al., 1986) shown that the type of sediment in location which had been the catching area of *A. pleuronectes* was silt and mud. It indicated that the scallop in this area had long adapted on those both types of substrates, at least for more than 2 decades.

Scallop in the study area could be captured at 5-20 km from the estuary. Scallop were not found at a distance of < 5 km because it was too close to the mainland where many rivers flowing down to the estuary leading to a very high sedimentation avoided by scallop. Franklin et al. (1980) stated that *Amusium sp.* could be found distance from the estuary in order to avoid sedimentation. While the scallop was not found at a distance of > 20 km, it was allegedly because of the lack of data catching on that distance. Fishermen might notice the economical value if they had to reach a distance over 20 km considering the high cost expended just to reach such distance.

Scallop at the study area were mostly captured on the current velocity ranged from 0.07-0.09 m/sec and were not found in other current velocity range, either weaker or stronger (Figure 3e, 4e). However, when the current velocity was relatively strong to medium, only 2.8 %, then it was ignored, thus scallop tended to choose a location with a stronger current velocity from the existing current in all the study areas.

Water current played an important role for the suspension-feeder organism to get their food as well as food reserves distribution from one location to another. With relatively limited movement, suspension-feeder benthic organism relied a lot on water current near the seabed to obtain food reserves (Mortensen, 2001).

Scallop had a preference of the seabed with higher salinity than the average salinity of the study area (Table 4, Figure 3g, 4g). Low salinity at the study areas was located in the waters close to the mainland, especially around the estuary in the eastern part of study area and relatively high salinity was found in open ocean. In contrast to the salinity in the deep sea that was relatively homogeneous (Gage and Tyler, 1996), salinity in shallow waters was fluctuated (Gross, 1990). Lower salinity around the mainland was due to the input of freshwater from the mainland through the rivers.

All organisms had optimal salinity for its life including scallop. Salinity affected the diffusion of oxygen vertically (Hutabarat and Evans, 2000), therefore it effected the organisms and the environment living in it. In addition, salinity was also a determining factor on the organism growth and survival. By having the ability to migrate, *Amusium* sp. (though limited), allowing these species to search suitable seabed salinity as its habitat.

The temperature distribution pattern in the study area was inversely to the depth gradient (Figure 3f, 3b). The entry of warmer water from the river, followed by shallow water, had caused temperature around the estuary in the west tended to be higher. In the shallow areas, the penetration of sunlight could penetrate deeper into the waters so that the temperature at that location was higher if compared to the deeper waters. While in front of the Pemali River in the east, with deeper water depth, temperature was relatively low even at a distance that was not too far from the estuary (Figure 3b).

Although the temperature range of the seabed waters at the study area was relatively homogeneous, scallop had a special preference for temperature conditions. These species tended to choose the lower temperature than the temperature in the entire study area (Figure 3f, 4f). Tropical fish species, including scallop, could not grow well at temperatures below 24 °C whereas the tolerable daily temperature change in laboratory was 4 °C at most (BBL Ditjen Perikanan, 1994).

Marine organism including scallop was generally cold-blooded animals in which body temperature was strongly influenced by the temperature of the surrounding environment and did not have the ability to adjust its body temperature. With low temperature, the rate of metabolism did not work too fast, so that the energy savings used for both growth and reproduction were more.

Based on the spatial distribution of the pH of the seabed, scallop was found in a location with high pH (> 7.3) (Figure 3h, 4h). Changes in water pH were influenced by photosynthetic activity, temperature, and waste disposal (Beveridge, 1987). Widowati et al., (1999) added that in Pekalongan waters, scallop *A. pleuronectes* were found in waters with pH tended to be alkaline. The seawater was generally alkaline with pH range between 7.5 and 8.5, because the relatively stable chemical composition contained. Seawater also had a good buffer system so that the pH value was relatively stable, due to the addition of alkali or acid compounds proportionally (Beveridge, 1987). Effendi (2003) also added that a low pH value (6-6.5) might lead to a decrease diversity of plankton, thus reducing food reserves for marine organism.

In contrast to the surface, pH generally tended to be more alkaline (~8), pH of the seabed at the study area tended to be lower. Depth and type of substrates factors determined the pH value in which the level of acidity in the deeper regions was relatively low compared to more shallow areas (Usman, 2006).

Habitat suitability of scallop at the study area could also be proved by biological data in the form of scallop length distribution during the catch period of 2008-2010 (Widowati et al., 2008; Prasetya, 2009; Kristianti, 2010). Suitable habitat allowed an organism to grow and evolve during their life cycle in the same location. This was supported by the discovery of scallop with various sizes from small to a ready-catch size (Figure 6) at the same location (Figure 5).
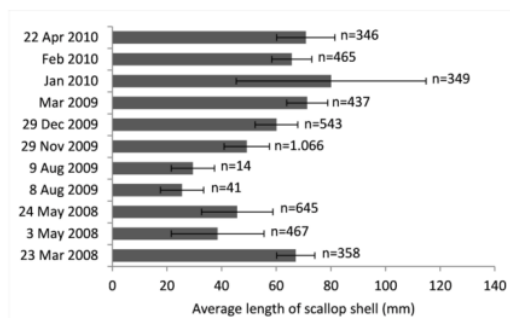

Figure 6 Scallop shell length based on catching period in Brebes District waters (Source: Widowati et al., 2008; Prasetya, 2009; Kristianti, 2010)

ENFA model validation using AUC method produced values of 0.94 (~1) showed that the model could be said to be accurate and was very good (Hirzel et al., 2006) for modeling scallop habitat in Brebes District. The suitability maps resulted from the spatial modeling and ENFA could be used as a guide for fishermen, thus it could increase the efficiency of fishing effort. Local government through the Department of Marine and Fisheries Affairs in Brebes District could utilize the habitat suitability map of scallop as fisheries management guidelines, particularly in providing spatial information of scallop habitat.

4 Conclusion

The conclusions from this study were as follows: Suitable habitat for scallop *Amusium pleuronectes* in Brebes District waters was seabed with very different conditions from the average habitat conditions existing in the entire study area (p <0.05). The suitable habitat was seabed with high plankton density (11,001-14,500 ind/L), between 18-31 m water depth, low suspended solids (<3.61 mg/L), fine sediments (mud, $\varphi \geq 6$) and a relative distant from estuary (> 5 km). In addition, the scallop also required habitat with high current velocity and salinity (> 0.06 m/sec; 31.85-32.65 ‰) and relatively low temperature (29.92-30.06 °C), while for the pH level, scallop were relatively more tolerant (7.3-7.4).

Based on spatial modeling of scallop habitat suitability in the study area, there were three categories classified as follow: 1) suitable habitat categories covering 4,629.01 ha (5.8%); 2) marginal habitat 9,291.09 ha (11.5%); and 3) unsuitable habitat covering an area of 66,682.68 ha (82.7%).

The suitable habitat for the scallop was at the eastern seabed of the study area located relatively far away from Pemali River estuary. Marginal habitat was around the suitable habitat, while the unsuitable habitat was outside area of both categories as mentioned before, mainly located near the mainland, in the central and western parts of the study area.

ENFA model could be said to be accurate and was very good for modeling the habitat of scallop in Brebes District with validation value of 0.94 (~1) using the AUC method.

Acknowledgement

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